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RAFAEL MARIÑO
DE NUEVAS TECNOLOGÍAS
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The role of golden hydrogen in the decarbonising of urban buses

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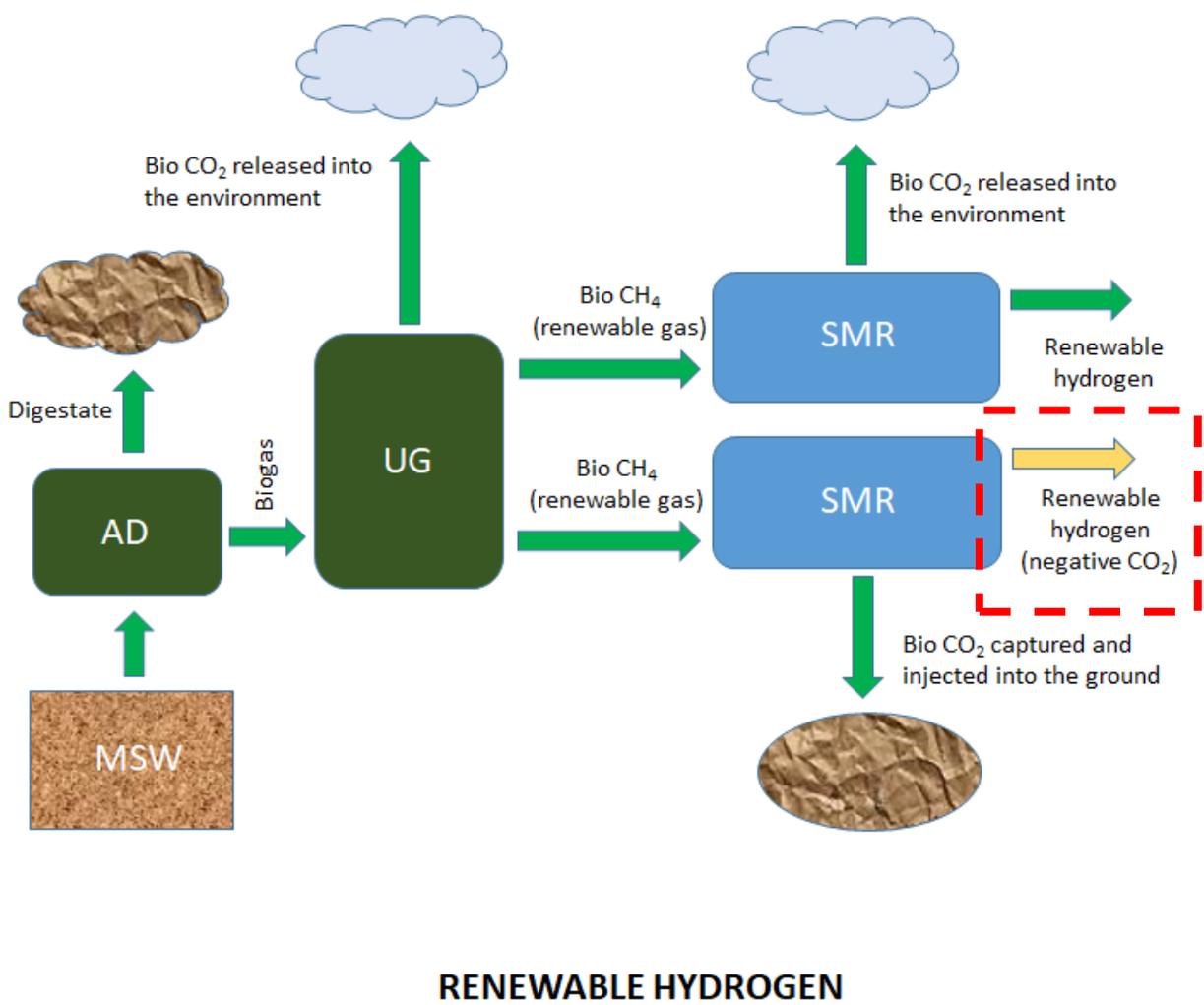
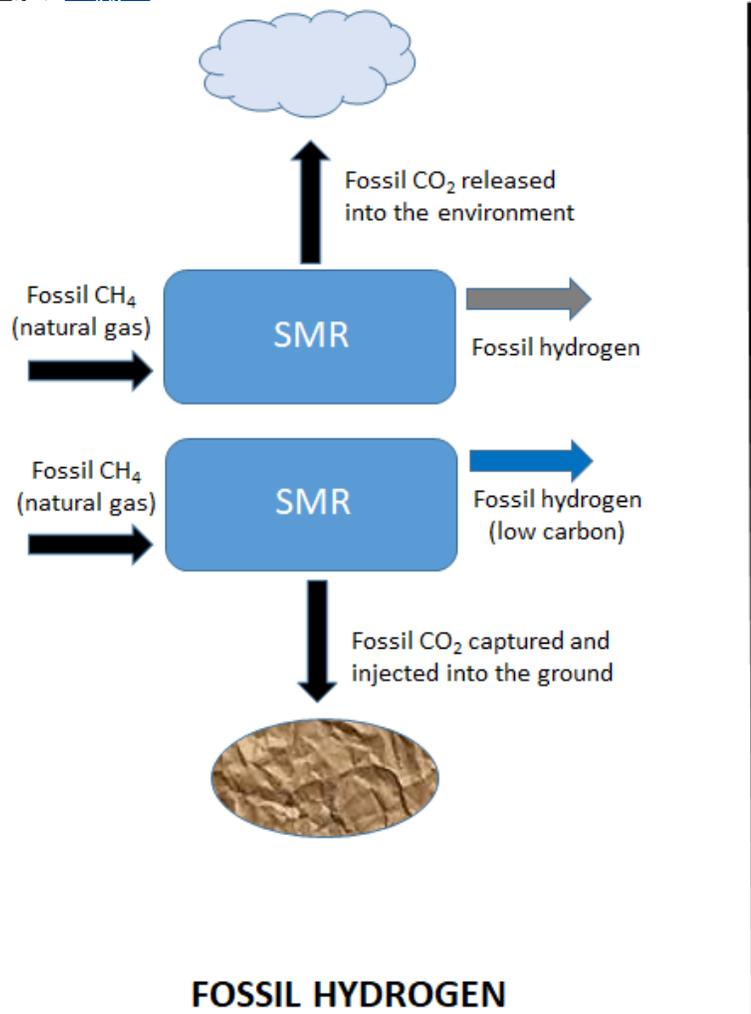
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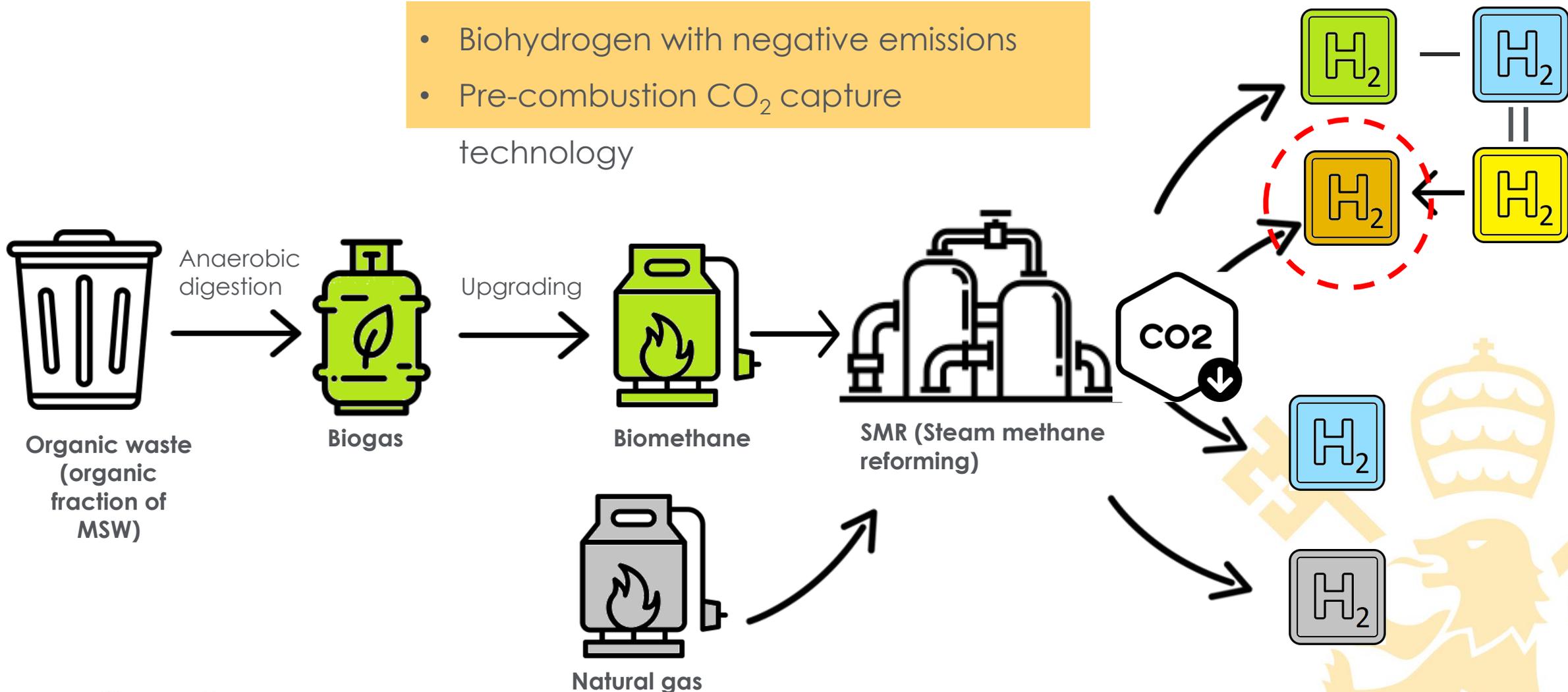
⁴Centre for the Development of Renewable Energy Sources (CENER) / Research Centre for Energy, Environmental and Technology (CIEMAT)

What is *golden* hydrogen?



What is *golden hydrogen*?

- Biohydrogen with negative emissions
- Pre-combustion CO₂ capture technology



What is new?

[HARENSES, 2022]

Repsol produce hidrógeno a partir de biometano en una refinería española

UPSTREAM ONLINE / 05 OCTUBRE 2021



GAS

El hidrógeno se utilizará en la producción de combustibles como gasolina, gasóleo o queroseno para la aviación.

[Upstream Online, 5/10/2021]

[Bayo Tech presents lo scale reformes for MSW. Negative emissions are produced if CO2 is captured]



Hydrogen from biogas reforming will be been producen in Haro (Spain)

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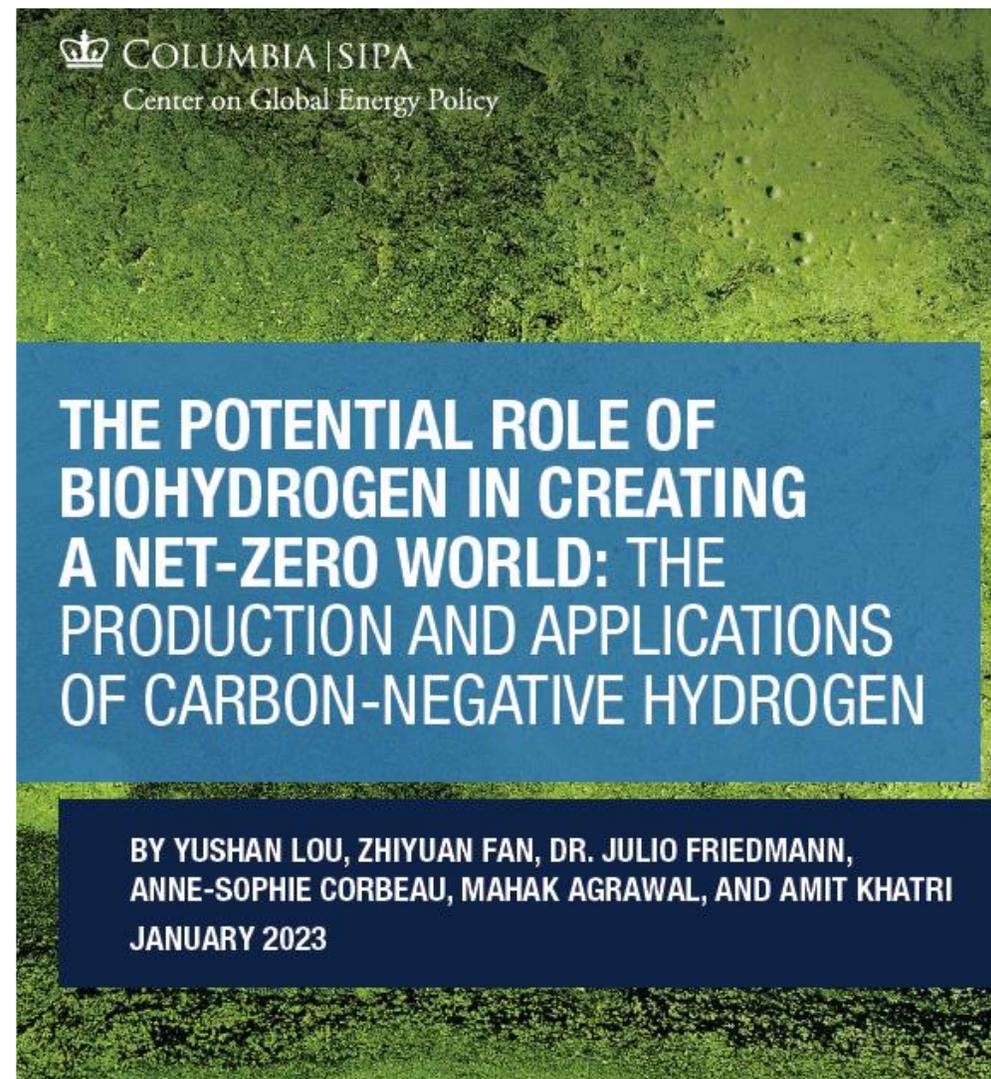


What is new?



comillas.edu [[EBA, 2023](#)]

- SMR of byohydrogen releases biogenic CO₂
- CCS generates **negative emissions**
- Golden hydrogen **avoids** fossil emissions replacing fossil fuels AND **compensates** unavoided emissions of other sources

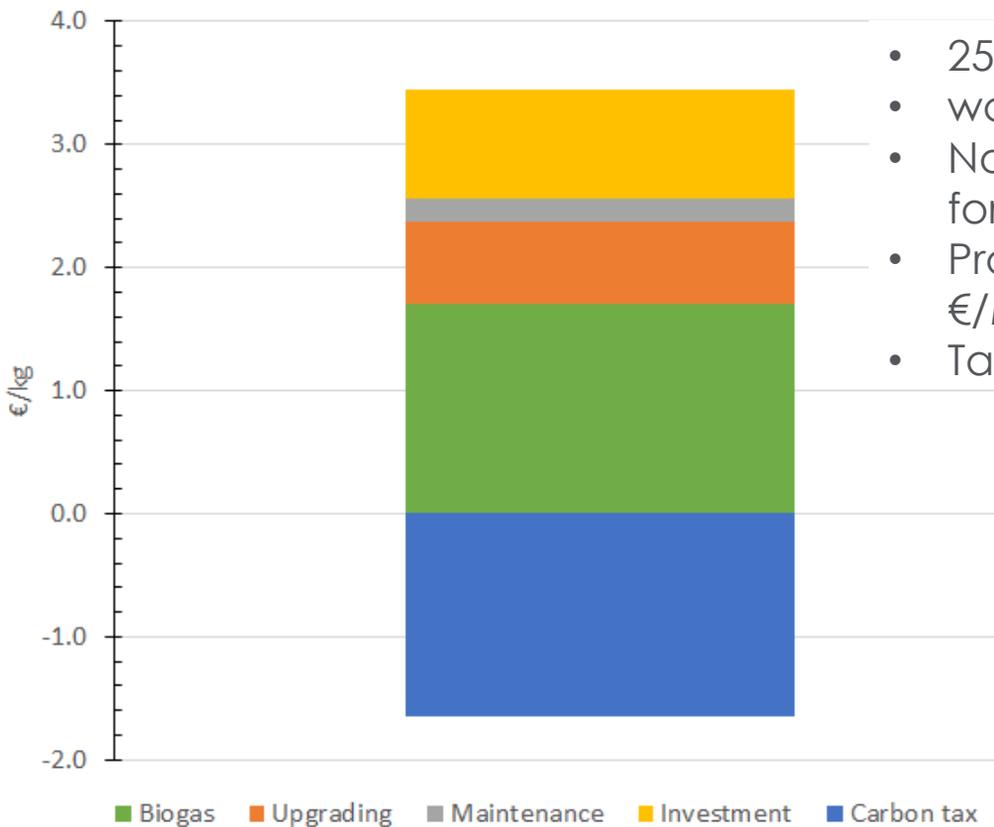


[[COLUMBIA/SIPA, 2023](#)]

Production and costs

Table 1. Conversion ratios for SMR with or without CO₂ capture (adapted from [19]).

	η_{smr} p.u.	HMR Nm ³ H ₂ /Nm ³ CH ₄	CHMR kg CO ₂ /kg H ₂	Capture efficiency %	CO ₂ captured kg CO ₂ /kg H ₂
Without CCS	0.759	2.52	8.74	---	0
With CCS	0.691	2.29	0.96	90	8.64



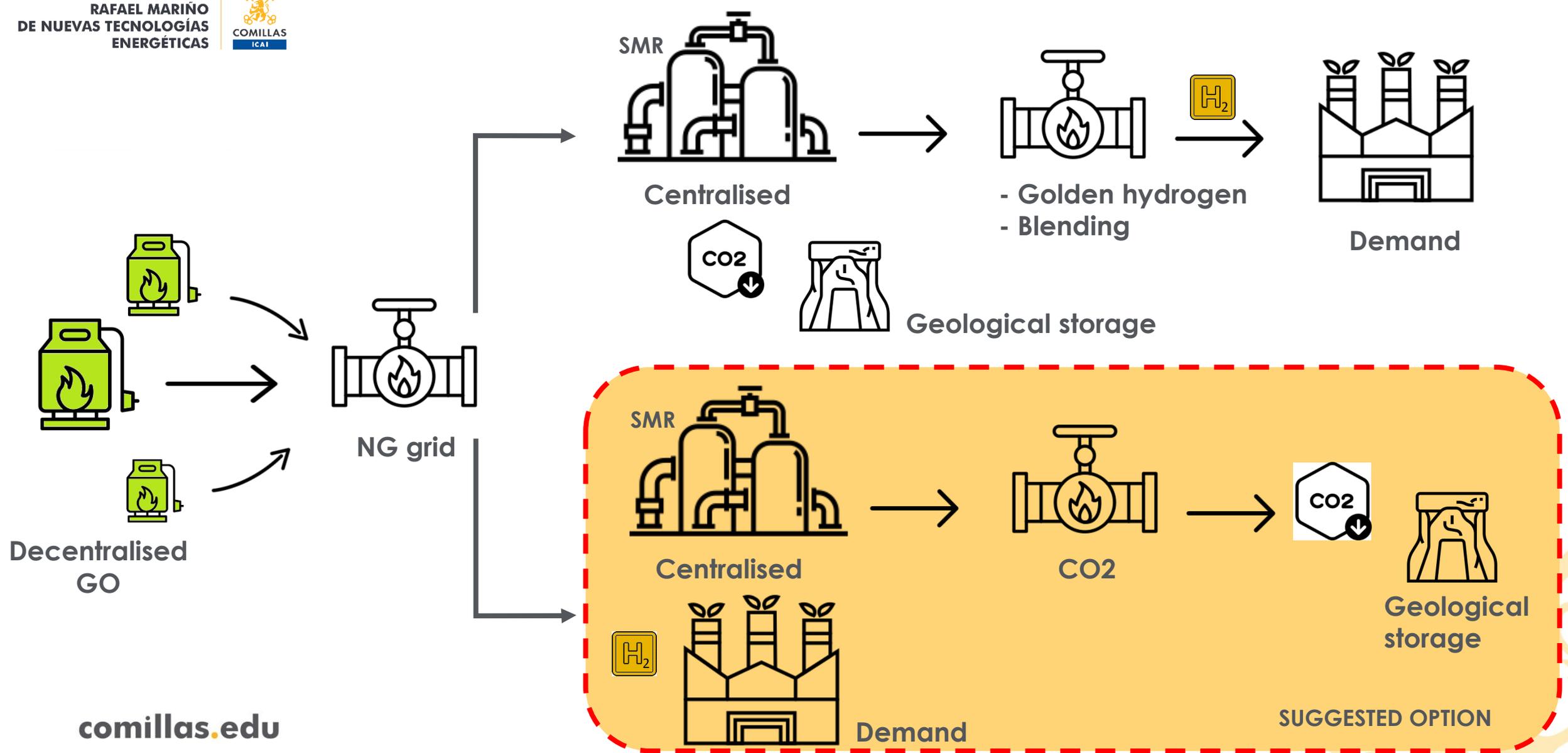
- 25 years lifespan
- wacc: 8%
- Nomnal escalation rate: 0% (8% for CO₂)
- Production cost of biogás: 35 €/MWh
- Tax for CO₂: 80 €/ton

Production rate from MSW:

- 2.56 kg H₂/year-pax in Madrid
- 3.85 kg H₂/year-pax in

Fuerteventura

Supply chain



FCEV as urban buses

10 FCEV in Madrid, with a green hydrogen refilling station (Dec 2023)



Bus 9051, Mercedes Benz O530 BZ (Citar Cell). Operated in Madrid in 2003 ([CUTE/ECTOS](#))

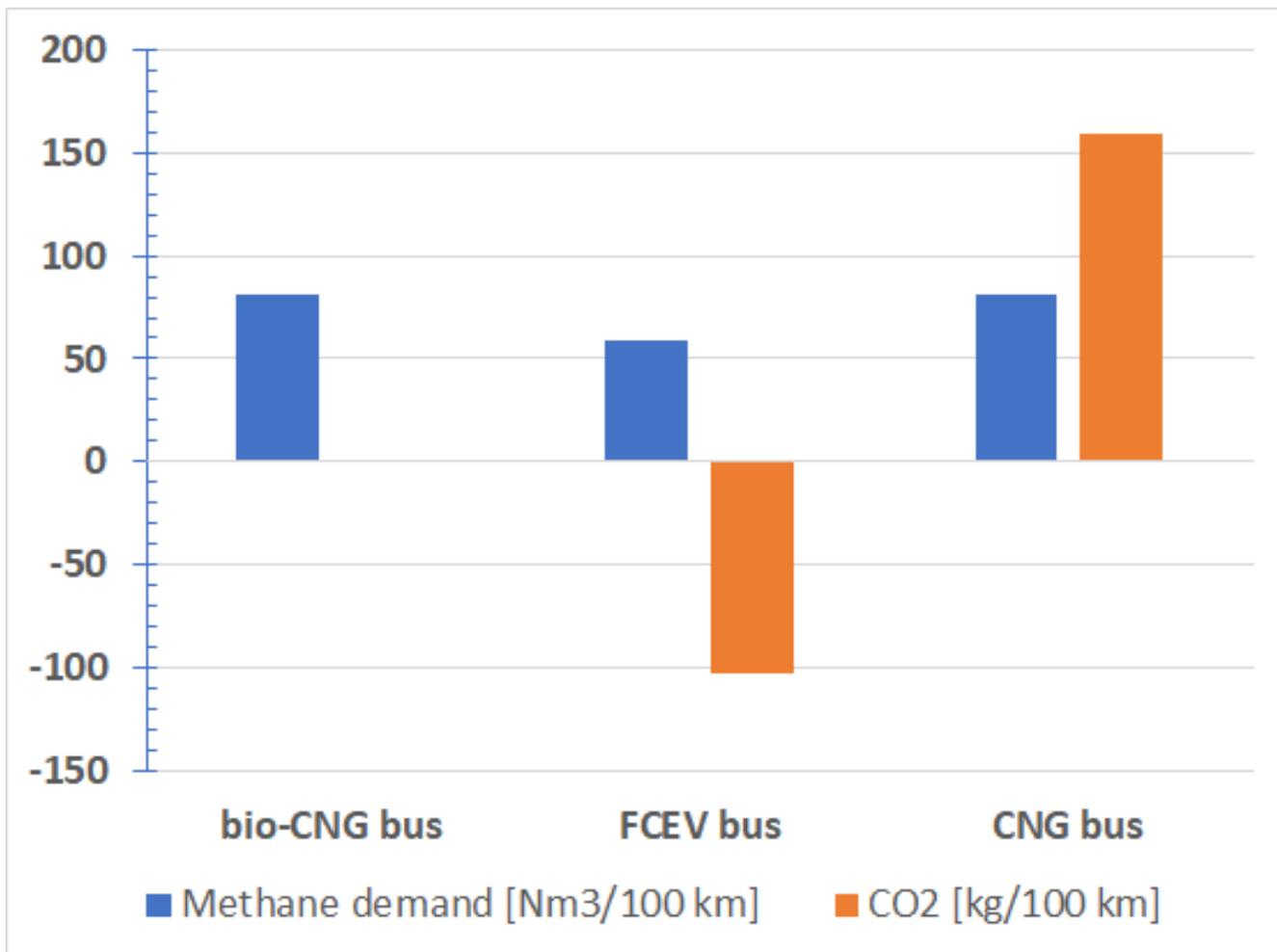
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20 years



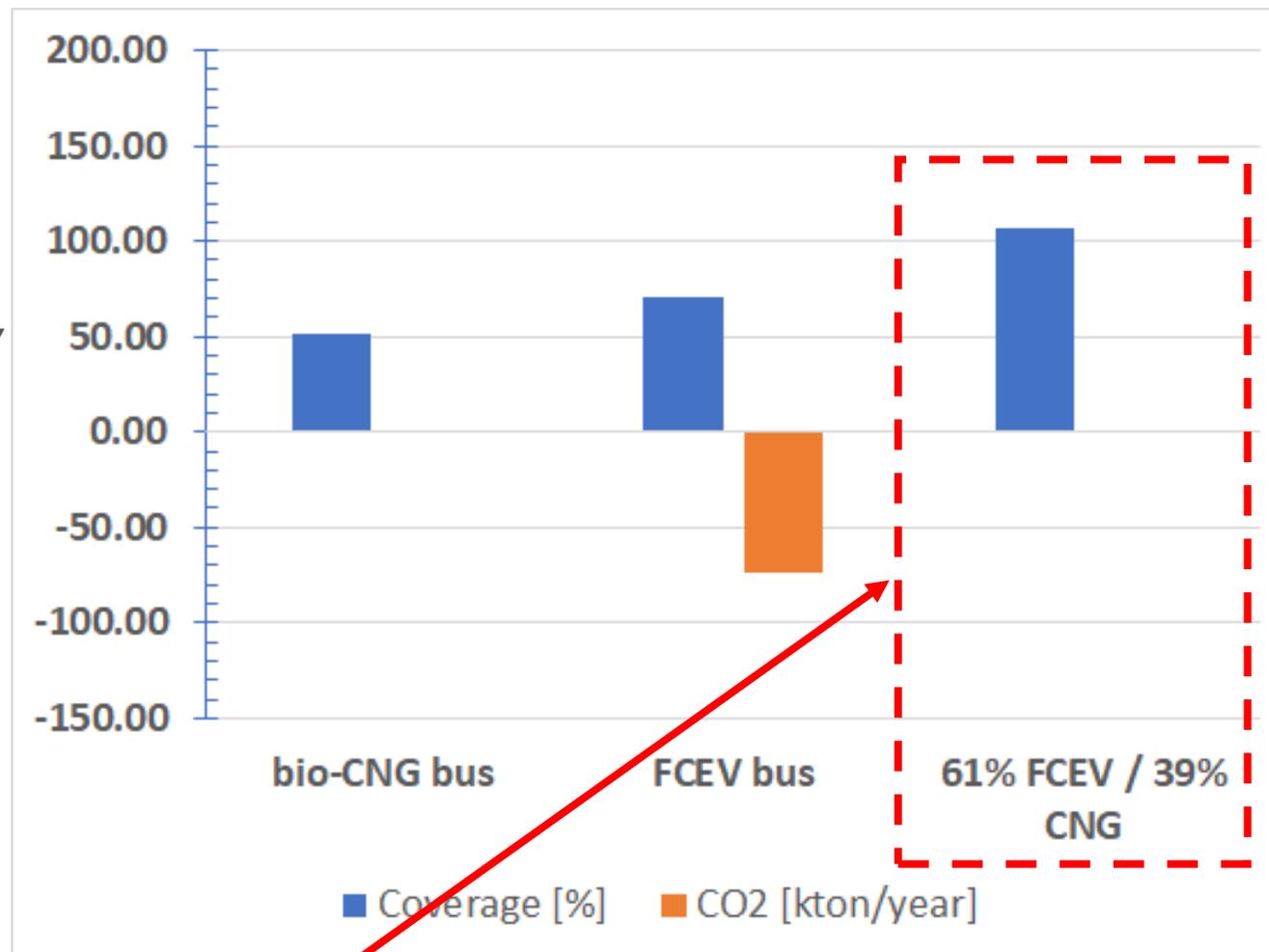
Results. Technology



- Golden hydrogen saves 28% biomethane
- Negative emissions would compensate 64% of fossil emissions of an ICE-NG bus
- FCEV consumption:
 - 12 kg H₂/100 km
 - 6.5 kWh-HHV/km (primary energy)
- ICE consumption:
 - 81 Nm³ CH₄/100 km
 - 8.9 kWh-HHV/km (primary energy)

Results. Madrid

- 3,334,730 inhabitants (Madrid city)
- 2049 buses
- 100,475,522 km/year
- Hydrogen demand for 100% FCEV fleet: 12,057 ton/year
- Production from MSW: 8,504 ton/year (70.53% demand)
- Cost of H₂ for FCEV:
 - 20.40 €/100 km including CO₂ credits
 - 39.84 €/100 km w/o CO₂ credits
- Cost of retail natural gas for ICE: 57.9 €/100 km



Results. Fuerteventura

- 116,186 inhabitants
- 35 buses (“guaguas”)
- 4,228,936 km/year
- Hydrogen demand for 100% FCEV fleet: 507.5 ton/year
- Production from MSW: 447.1 ton/year (88.1% demand)
 - Biogenic captured CO₂: 3,862 ton/year
 - Fossil CO₂ emitted by 11.9% fleet: 801 ton/year
 - Excess CO₂ credit: 3,061 ton/year
- Cost of H₂ for FCEV:
 - 32.16 €/100 km including CO₂ credits
 - 51.48 €/100 km w/o CO₂ credits
- Cost of retail natural gas for ICE: 115.8 €/100 km



Conclusions

- Self-produced biohydrogen from MSW with CO₂ negative emissions has been proposed for urban buses
- Net-zero urban buses is achieved, even maintaining fossil ICE fleet share
- ETS (carbón taxes) in transport reduces costs (when available)
- Competitive prices with retail natural gas
- CO₂ should be removed from atmosphere: geological storage or usage in circular products. This latter option would avoid CO₂ transportation if usage facility is in the SMR one.



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Thanks for your attention

Questions?

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